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THESIS

AN EVALUATION FRAMEWORK FOR DESIGNING A NIGHT VISION, COMPUTER-BASED TRAINER

by

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December 1993

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A framework is presented in this thesis that includes a review of the technology available for designing a night vision CBT. System attributes and constraints are identified and analyzed, and evaluation criteria developed to allow for examination of alternative system configurations.

Two configurations are developed: one PC-based and one workstation-based. These configurations present different cost/benefit components. A sample in graphics capabilities, processor performance and peripheral support is provided for the two configurations. In addition, cost range estimates are included and possible baseline capabilities established to assist in the determination process.

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AN EVALUATION FRAMEWORK FOR DESIGNING A NIGHT VISION, COMPUTER-BASED TRAINER

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ABSTRACT

The mission requirement of low-level, nighttime navigation employing night vision goggles has expanded. This has led to a greater demand for training NVG skills and initiated a requirement for a low-cost, desktop, computer-based trainer (CBT).

A framework is presented in this thesis that includes a review of the technology available for designing a night vision CBT. System attributes and constraints are identified and analyzed, and evaluation criteria developed to allow for examination of alternative system configurations.

Two configurations are developed: one PC-based and one workstation-based. These configurations present different cost/benefit components. A sample review in graphics capabilities, processor performance and peripheral support is provided for the two configurations. In addition, cost range estimates are included and possible baseline capabilities established to assist in the determination process.

TABLE OF CONTENTS

I. INTRODUCTION

A. BASIS FOR EVALUATION

In order to prepare aircrew for the expanding role of night vision employment in fixed-winged aircraft, a low-cost, portable, computer-based trainer (CBT) needs to be developed. This part-task trainer will focus on enhancing aircrew proficiency and confidence, attributes that directly relate to improved combat effectiveness and greater safety of flight awareness.

The mission expansion in night vision has required aircrew to develop a more thorough training syllabus, especially while deployed. A CBT that incorporates a representative head-mounted display will enable aircrew to simulate flying in the night vision environment and support a tactical doctrine that requires a low-level, nighttime strike capability.

Designing an framework for evaluating the associated computer technology is the initial stage of the project. This framework will be utilized to assist in the selection process for the prescribed desktop trainer.

B. GENERAL METHODOLOGY

This thesis will initially focus on determining possible system design requirements. Certain limitations exist, such as uncertain user requirements, potential changes in

specifications and a short developmental time frame. Evaluation criteria will be identified that could be used to assist in the assessment of available computer technology and head-mounted displays.

A framework will be constructed using a structured approach to design the system capabilities. This framework will be used to identify and compare alternative configurations for a CBT and ascertain their respective capabilities and costs.

Finally, a practical example will be presented to help the reader understand the possible trade-offs between capabilities and costs.

C. SCOPE OF THESIS

This thesis will present general discussions of candidate computing systems. Capabilities across a broad spectrum will be discussed and price ranges presented.

Because these specifications are subject to change in the highly dynamic computer industry, estimates are intended to give the reader an overall view of possible alternatives, and should not be construed as definite figures.

1. Research Objective

The objective of this thesis can be stated as follows:

Design an evaluation format that will introduce evaluation criteria for possible alternative configurations,

identify current computer technology, and present a practical application of the established format framework.

D. BACKGROUND

Perhaps the most perishable skill in flying fixed-wing, tactical aircraft is nighttime, low-level, terrain-following navigation, employing night vision goggles, at speeds in excess of 400 nautical miles per hour (knots). It is extremely difficult to stay proficient in this labor intensive environment, especially while deployed. Loss of spatial awareness, poor flight discipline and airborne mishaps are the result of inadequate preparation and insufficient training. Lessons learned from participating aircrew and their respective airwing commanders during Operation Desert Storm confirmed the inadequacies of current, established procedures [Ref. 1: p.II-3]. The potential for loss-of-life in both training and operational sorties exists and is clearly unacceptable.

Since airborne training time aboard an aircraft carrier allows for only minimum attention to many mission requirements, a CBT, with accurate graphical representations of real-world scenarios and an available interface to a head-mounted display, would provide a low-cost, available and easy to use training tool to the applicable aircrew.

This CBT would allow for advanced, realistic training of a unique environment that requires aircrew performance to

deviate from normal procedures. Visual cues and spatial orientation while wearing night vision equipment are vastly different from those employed during routine operations (examples being restricted field-of-view and lack of depth perception), not to mention wearing a somewhat cumbersome piece of head-mounted hardware, in addition to the helmet.

E. ORGANIZATION OF THE THESIS

The thesis is organized as follows:

1. Chapter II. Design Concerns

This chapter focuses on the requirements for designing a CBT and the possible changes in system specifications. Issues addressed include current simulation techniques, computer technology trends and the emphasis on off-the-shelf procurement. A methodology is introduced to:

1. Help identify specifications and constraints.
2. Discuss data collection techniques.
3. Present possible alternative configurations.

2. Chapter III. Framework

In this chapter, an evaluation framework is established and the evaluation criteria is defined and discussed. These criteria will help clarify issues such as system performance, peripherals and component capabilities.

The design of the format follows a sequential approach with each component step discussed.

3. Chapter IV. Application of Framework

The chapter defines the functional components of two candidate systems, a personal computer and a workstation. These components consist of peripherals, the monitor, the head-mounted display and the internal architecture of the computing system.

A discussion of the evaluation criteria is presented and general cost ranges provided to help quantify the evaluation. The component capabilities and costs are formulated and presented in tabular form in Appendix A and B. Although the selection process is outside the scope of this thesis, a brief discussion recommends possible avenues to follow in the selection process.

II. DESIGN CONCERNS

A. INTRODUCTION

The design of a CBT for training NVG skills presents some interesting issues. Since a CBT of this kind has yet to be developed, there is little background data to review. Consequently, uncertain user requirements and changes in design specifications must be anticipated. In addition, the time frame for development should be relatively short, in order to make this system available to operational users as soon as possible.

1. Uncertain User Requirements

Little historical information exists to quantify the user requirements for this CBT. Only through an in-depth evaluation of the participating aircrew can a truly representative system be constructed. This would involve extensive interview and survey of aircrew currently flying fixed-wing aircraft such as the F/A-18, the AV-8B and the A-6. These aircraft are night vision compatible and the respective aircrew are the most qualified to make valued inputs. However, compiling these inputs into a coordinated list of requirements is both time and labor intensive. Consequently, until the user requirements can be defined, the design requirements of a CBT must be at a high level, at least

initially, to allow for redesign to better meet user demands.

2. Anticipated Change in Specifications

Although system specifications have been established (they will be discussed later in the chapter), they are still flexible, until they can be applied to the operational environment. Once applied, changes to these specifications must be anticipated to minimize avoidable delays in development.

3. Short Developmental Time Frame

In order to meet the requirement for a desktop trainer to supplement current aircrew training, this system must be developed in a short time frame. Because of the expansion of the mission requirement for night-vision, operational aircrew must immediately supplement their training syllabus.

Before pursuing the actual design methodology, it is important to discuss current simulation techniques, computer technology trends and the emphasis on commercial off-the-shelf procurement.

B. CURRENT SIMULATION TECHNIQUES

1. Large Scale Simulators

Airborne simulation has traditionally been conducted using large scale simulators, normally incorporating complete cockpit replication. These simulators are extremely expensive and take several years to develop and implement. Most utilize an entire building to house the cockpit, the simulation

environment (usually in the form of a domed room), and a mainframe computer to drive the simulation software. These systems provide aircrew with realistic representations of different airborne environments, as well as real-time inputs from an operator console. They are designed primarily for initial training of aircrew, with emphasis on proper cockpit and airborne discipline. The secondary mission is fleet refresher training for operational squadrons.

Obviously, the support requirements are enormous, with full-time personnel staffed for daily operation. Due to upgrade requirements, there is a certain amount of down-time inherent in these systems. This down-time can range from days to weeks, depending on the system.

C. COMPUTER TECHNOLOGY TRENDS

1. Reduced Distinction Between PC and Workstation

The advancements in computer technology have allowed the personal computer to accelerate its performance capabilities.

Many workstations, prior to two years ago, had a performance advantage over personal computers because of a superior central processor unit (CPU). However, the Intel 486 chip has provided clock speeds of 66 MHz, which is equal to many popular workstations, and superior to some.

Overall system performance cannot be measured by clock speeds alone, but it helps to demonstrate that the performance

gap between the two classes of computers is narrower than ever before.

2. Dynamic Environment

Computer technology continues to change so quickly that it is often difficult to remain current on many of the latest innovations. Capabilities continue to increase, almost exponentially, while cost and system size decrease. Information gathering has evolved into a science, with commercial publications, trade journals and technical publications inundating the computer market. It is incumbent on any researcher to survey as many sources as possible in order to make quality decisions about computing products.

3. Improvements in Graphics Technology

Dedicated graphics processors, known as accelerators, have relieved much of the graphics processing burden on the CPU and allowed for 24-bit (16.7 million colors) graphics operation. Software reconfiguration of the screen resolution allows for full use of the processor's available memory, normally between one and two megabytes. This provides graphics resolution of up to 1600 x 1200 pixels. [Ref. 2:p.40]

D. EMPHASIS ON COMMERCIAL OFF-THE-SHELF PROCUREMENT

Their is currently great emphasis within DoD on increasing the use of commercial off-the-shelf (COTS) products. These products require very little government development and are

normally very accessible. Some principal advantages of this approach are the following:

- Research and development costs are reduced, sometimes eliminated.
- Current technology can be immediately procured.
- User requirements, once identified, can be quickly satisfied.
- Development and implementation time is greatly reduced.
- Increased competition from multiple sources can cause reductions in costs. [Ref. 3: p.22]

There are disadvantages to this procurement policy and they include:

- Commercially-procured items often must be assigned a MILSPEC number, noting that it meets military specifications for reliability and safety.
- Logistical support issues and training can cause increases in life cycle costs.
- Tradeoffs in cost and performance is sometimes inevitable in order to accommodate commercial components. [Ref. 3: p.23]

Many of the disadvantages can be offset with proper life cycle management and through commonality of components. Planning for delays in inspection and for integration of training requirements for similar system elements will reduce the administrative burden of off-the-shelf procurement.

E. METHODOLOGY

In order to address the design concerns, a systematic approach was utilized.

Initially, overall system specifications, including constraints, were developed.

Next, a survey of available resources was conducted, using data collection from various sources. This provided information on currently available commercial equipment in the area of desktop simulation and identified the criteria critical to the evaluation of a CBT.

Finally, alternative configurations were designed to allow for evaluation and comparison in price and performance. This step is also the precursor to the selection and construction phases in traditional prototype life cycle development. [Ref. 4: p.15]

This technique was preferred because of the previously discussed issues of uncertain user requirements, possible specification changes and the need to be operational in a short time frame.

1. System Specifications

Four specifications were identified. They are realistic graphical display, development of a night vision database, compatibility with head-mounted displays, and deployability of the system.

a. *Realistic Graphical Display*

The graphics presented should be as even and fluid as possible to provide realistic simulation for the aircrew. The display must be refreshed in such a way that the aircrew can respond to the simulated visual cues of the landscape.

A problem presents itself in this area. What is representative? Is full-motion video required or would something less fluid provide acceptable training. The only way to determine acceptability would be to directly survey the users, allowing them to view different presentations and measure them against actual operational sorties. For the purpose of this thesis, generally accepted baseline values will be discussed in the next chapter.

b. *Development of a Night Vision Database*

This database will contain graphical presentations consisting of digitized data from various sources. The construction of these presentations is demanding and laborious. If a representative database is not available in time for system development, a video input source, such as full-motion video, would be substituted.

(1) Difficulties in Production. Very few, if any, night-vision databases have been produced. Reasons include:

- Accurate shading representations are very complex. Ambient light conditions are governed by atmospheric conditions (clouds, fog, haze) and lunar stages (full, half, etc...).

- Blooming (white sparkles) is hard to simulate.
- The generation of the depth perception limitation, due to the loss of visual cues, requires the employment of strenuous techniques for accurate presentation.
- Creating representative terrain maps are extremely time intensive, even using developmental tools that can capture digital mapping data. Converting the data into different shades of green significantly delays database configuration.

c. *Compatibility with Head-Mounted Displays*

The technical capability of available computing hardware might alleviate the requirement of training while wearing a head-mounted display. Many systems might provide the resolution and the graphical representation required, on a monitor, but realism would be sacrificed. The training issues of restricted field-of-view (FOV) and reduced depth perception can only be addressed by using a head-mounted display.

d. *Deployability*

One of the biggest factors in the system's requirements involved the ability to deploy the system onboard an at-sea aircraft carrier or perhaps an airwing on detachment. The CBT must be available to the aircrew when they are not at their home base and that requires a system that is compact and rugged enough to withstand frequent transportation.

e. Constraints

Three constraints are evident. The first, and probably most prohibitive, is cost. DoD procurement policies require close scrutiny of cost factors. The other two constraints are timeliness of final system delivery and system complexity.

(1) Costs. A shrinking military budget mandates that procurement policies aim for the most value/performance for each dollar spent. Replacing large legacy programs with smaller, cheaper, operational-specific systems are underscored. Consequently, this system must meet those congressionally-legislated requirements.

Any procurement decision must analyze incurred costs in areas of bulk versus single purchase, available government furnished equipment (GFE) versus independent contract and price discounts for governmental use.

(2) System Delivery. The mission requirement of low-level flight using NVGs will continue to expand and the training and proficiency of the aircrew must augment this expansion.

Undue delays in the areas of analysis, procurement and development must not manifest themselves, because the trade-off could be human lives. As previously discussed, proper life cycle management would help prevent possible delivery slippage.

(3) System Complexity. The system must be easy to use. Users must be integrated in the development phase to ensure that simplicity is provided. Tutorials, both software driven and in written text, must be included in the final delivery. System training, provided by appropriate vendors, can provide expertise and furnish much needed proficiency.

2. Survey and Data Collection

Collecting the information on this project involved conducting direct interviews with marketing representatives from computer companies and published specialist in the field of desk-top simulation, reviewing computer periodicals and directly interacting with technical experts.

a. Interviews

Consultation with representatives from Evans and Sutherland, Silicon Graphics and Kaiser Electro-Optics provided invaluable insight into system development. Both hardware and software requirements were discussed and alternatives identified. Procurement costs were also supplied.

Essential information on system component construction, possible database requirements and a list of features for desktop simulation applications was also obtained through the interview process. [Ref. 5: p.486]

b. Computer Periodical Review

Computer periodicals, especially *Imaging World*, *Silicon Graphics World*, *PC Magazine* and *Computerworld*, are a valuable source of current computer technology. Discussions in the domains of hardware comparisons, software development and graphics presentation proved enlightening and are a valuable basis for evaluating system requirements.

c. Consultation with Technical Experts

Discussions on head-mounted displays were conducted with technical representatives of Optics One and Kaiser Electro-Optics.

A demonstration of the Sim-Eye head-mounted display from Kaiser enabled a first-hand evaluation of its capabilities in the areas of FOV and focus range. It also provided a user's prospective on size, weight and durability of the head-mounted display.

3. Alternative Hardware Configurations

Analyzing different system configurations provide qualitative measurements of overall performance capabilities and physical system set-up and storage requirements.

Designing alternative configurations will enable direct input and feedback from designers and users. Hard system requirements like monitors, head-mounted displays and workstations/personal computers can be supplemented with peripheral combinations of CD-ROM, laserdisk, video tape and

other external storage devices. I/O devices consist of a keyboard and mouse for system manipulation and a joystick for realistic flight simulation.

Comparison between alternatives allow for a more comprehensive cost/benefit analysis.

III. FRAMEWORK

A. INTRODUCTION

Constructing a framework for evaluating technology associated with this desktop CBT will require a incremental process that identifies evaluation criteria and then applies those criteria to the functional requirements. This chapter will focus on the evaluation criteria before discussing the actual framework construction. This framework is broad in nature and allows for a range of alternatives to be presented.

1. Requirement for Effective Analysis

Although the system that is being proposed in this thesis is potentially a low-end simulator, it is imperative that an accurate analysis is conducted to focus the developmental effort. Because many computing systems may meet the criteria, an effective evaluation would narrow the choices and highlight the candidate(s) that best meet the requirements of the users.

2. Methodology

The evaluation criteria will be examined to help define the framework. Consequently, the framework will be constructed using four step process that is general in nature to allow for across platform evaluation.

B. FRAMEWORK

1. Evaluation Criteria

The following is by no means an exhaustive list. It is, however, a preliminary set of measures that can be used to analyze a CBT. These items were a compilation of the collected surveyed information. Each criteria is discussed briefly and quantitative measurement factors supplied, when possible, to assist in the evaluation process.

a. Performance

Computing performance consists of processing and graphics capability. The Central Processing Unit (CPU) performs the critical functions of any computer system, notably the processing of vast amounts of instructions required to run the computer applications. The unit of measurement of the CPU, referred to as clock speed, is either megahertz (MHz) or millions of instructions per second (MIPS).

The graphics capability is crucial to overall system performance. Realistic graphics, displayed either real-time or retrieved from system storage, should be a representative, real-world simulation. As previously noted, only the users can determine if the simulation is representative.

(1) Processing Capacity.

- <u>Benchmarks</u>: In order to test system performance across different platforms, measurement tools, called benchmarks, provide quantitative results, normally in the form of

numerical values. The higher the value, the better the performance of each respective system on a given application. However, care must be exercised when performing benchmark testing or using benchmark results. The tested platforms must be of similar configurations and, if possible, the use of applicable applications and data files employed. If the user environment cannot be duplicated, benchmark measurement could be inaccurate. Also, benchmarks are sensitive to the type of computing, e.g., integers vs. floating point. Normally, single-user systems can be effectively benchmarked; multi-user systems are more difficult. Industry benchmarks include Dhrystones, Whetstones, Khornerstones, SpecInt and SpecFP. [Ref. 6: p. 3]

(2) Graphics Capability.

- Refresh Rate: In order to provide a realistic presentation, it is generally agreed from the data collected, that the refresh rate must be at least 30 Hz (30 times/second). Faster rates are preferable. The lower the rate, the more rigid the presentation (i.e., the displayed picture "jerks"). It must be stressed that refresh rates increase with a smaller displayed "window" or section on the monitor. In other words, if only one quarter of the monitor were to display the simulation, it would refresh at a higher rate than if the entire monitor was being used. For the purposes of this evaluation, the full monitor presentation is recommended.

- Resolution: Available resolution is a factor of the application and the size of the monitor. The larger the screen size, the better the resolution. For 1280 x 1024 pixel resolution, a monitor of at least 17 inches is recommended in order to present small scale detail. Less resolution is required, and prescribed, for smaller monitors. For example, a 14-inch screen looks best at 800 x 600 pixels. Another factor to consider is dot pitch. A 15-inch screen with .31 mm dot pitch is equivalent to a 14-inch with a .28 dot pitch. This is because the displayed presentation must be condensed to fit the width of the smaller screen and making the higher dot pitch and resolution more difficult to read. [Ref. 7: p. 14]

b. Software Support

Applicable software must be identified or created in order to perform to the system specifications. Three areas of concern are presented.

- Availability of Existing Night Vision Visual Database: The time-consuming design phase of the visual database would be precluded if a representative night-vision database exists and is available. This determination might prove difficult because of the lack of available information. During data collection, none of the individuals surveyed were aware of an existing database.

- Tools for Database Design: Obviously, if one is not available, then the visual database must be constructed. Developmental tools, such as MultiGen, from Software Systems and Replicore, from Kinetic Visuals, provide three dimensional model building. Other tools are also available to perform similar functions.

- Access to DMA and USGS Data: In order to create real-world scenarios, rendering of Defense Mapping Agency charts and United States Geological Survey digital mapping data into the visual database is required. The tools previously identified support the inclusion of the digital data in database construction.

c. Peripheral Support

The system must be able to support a number of peripherals, the specifics of which will be discussed in Chapter IV. These peripherals will augment the CBT and increase overall system capabilities significantly.

- Interactive I/O Devices: A joystick would provide authentic airborne simulation. Additionally, a keyboard and mouse would provide user interface.

- Replay Capability: Training would be maximized if the participating aircrew were able to review their

performance and note any deficiencies. Additionally, this debrief capability could significantly enhance actual mission preparation by providing an avenue for critique of an actual mission rehearsal.

- Support of a Head-Mounted Display, Audio and Video Input Devices: These devices will provide the realism to the system simulation.

d. Migration Path

As technology continues to advance, the system must be capable of upgrading itself to incorporate greater capabilities and possibly integrate with more robust systems.

- Reusability of Components: Reusable components provide flexibility and cost savings and reduce the need for outside support requirements.

e. User Needs

Because specific user requirements are not currently available and are subject to change, a general list is provided to help provide guidance.

- Ease of Use/Learning: Because of the possible lack of computer literate users, the system simulation must be easily accessible with a tutorial provided to expedite learning and training.

- Acceptable MTBF: Reliability of the system when it is deployed is a relatively important issue. A mean-time-between-failure value must be determined before design to ensure the appropriate amount of "up time" is provided to the aircrew.

- Manage Specific Operational Profiles: Because of the myriad of mission specific profiles that aircrew must prepare for, the system must have available at least a representative simulation of prospective geographic terrain.

f. Management Issues

There are numerous managerial concerns. The following three issues are perhaps most important to initial system start-up.

- Availability of Clones: If warranted, the system software needs to be portable across multiple hardware systems if cost/availability issues are present.

- Vendor Viability: The vendor must provide the services required.

- System Mobility: Directly related to deployability, the system must be small enough, yet resilient, for frequent relocation.

g. Head-Mounted Display Component Capability

The actual display requirements could change with maturing technology. The following address existing and future growth areas.

- Liquid Crystal/Fiber Optic: Though not as mature, fiber optics provide better throughput and growth potential. Liquid crystal is more limited, yet prevalent.

- Refresh Rate: The head-mounted display must refresh itself at the same rate as the computing system.

- Field-of-View (FOV): The display FOV must be consistent with the night-vision goggle (NVG) FOV that is used by the aircrew.

- Monochrome/Color: Because a night-vision presentation is in shades of green, a color capable display is more realistic because it will support the different green hues. Monochrome only displays shades of grey.

h. Video Compatibility

Because of the potentially numerous video inputs to the system, both internal and external, compatibility with the head-mounted display is a concern.

- In Concert with Monitor: The head-mounted display must present the same picture as the system monitor. Training is enhanced with viewing by multiple aircrew members.

i. Design of the Head-Mounted Display

For realistic training purposes, the physical characteristics of the simulator device and the operational NVG model must match.

- Size/Weight: The head-mounted display must be similar in both size and weight to the NVG. Additionally, the display must be robust enough to withstand frequent physical transfer.

2. Design of Framework

Designing this evaluation framework required a systematic approach be utilized. This approach followed a four-step process. [Ref. 3: p.38]

1. Identify alternative configurations
2. Define functional components
3. Tabulate and compare capabilities and costs
4. Selection Process.

The alternative configurations were narrowed to two candidate systems, a workstation and a personal computer, both broadly defined, to preclude restriction in functional capabilities. In a realistic environment, more alternative candidates could be applied, but for the scope of this thesis, only these two were selected.

Defining the functional components was a direct result of reviewing the technology available by gathering applicable information and disseminating the data. The result is a component list that is somewhat general in nature, yet specific in capability.

Tabulating and comparing capabilities and costs would help identify possible fiscal constraints and trade-offs that would naturally result.

The selection process is based on cost/benefit measurements. Overall system performance must be measured against costs and other constraints.

a. Identify Alternative Configurations

Two hardware designs are presented. A pc-based system would provide a low-cost solution with a possible decrease in overall system performance. A workstation-based system delivers the computing power required for more realistic simulation with a significant increase in cost. Both alternatives are considered because they offer cost/performance alternatives.

b. Define Functional Components

At this point, it is difficult to determine exact functional components. However, using collected data from technical experts and operational users, a component list can be generated to provide specific guidance on the required components.

c. Tabulate and Compare Capabilities and Cost

Generating tables that list system capabilities and their respective costs, grouped by function, provide direct access in order to compare and contrast the different alternatives.

d. Selection Process

This process is based on selecting the alternative that maximizes benefit or value and still fits within defined system constraints. The selected alternative should meet the evaluation criteria to make it representative for the users. That criteria is subject to change once the user requirements are defined.

IV. APPLICATION OF FRAMEWORK

A. PURPOSE

This chapter presents the collected information of the alternative systems. The data, which is a review of current technology commercially available, is applied to the framework presented in Chapter III. The information, though cursory, will give the reader an idea of current computer technology.

B. APPLIED EXAMPLE

1. Identify Alternative Configurations

a. PC-Based

With the growth of the personal computer market, technological capabilities and computational power of the smaller, less sophisticated personal computer has increased dramatically. With the proliferation of the pc and related products, and the resultant competition in price, economically viable combinations of computer and peripherals are available. Figure 1 on the following page presents a possible hardware configuration that could deliver the prescribed performance requirements.

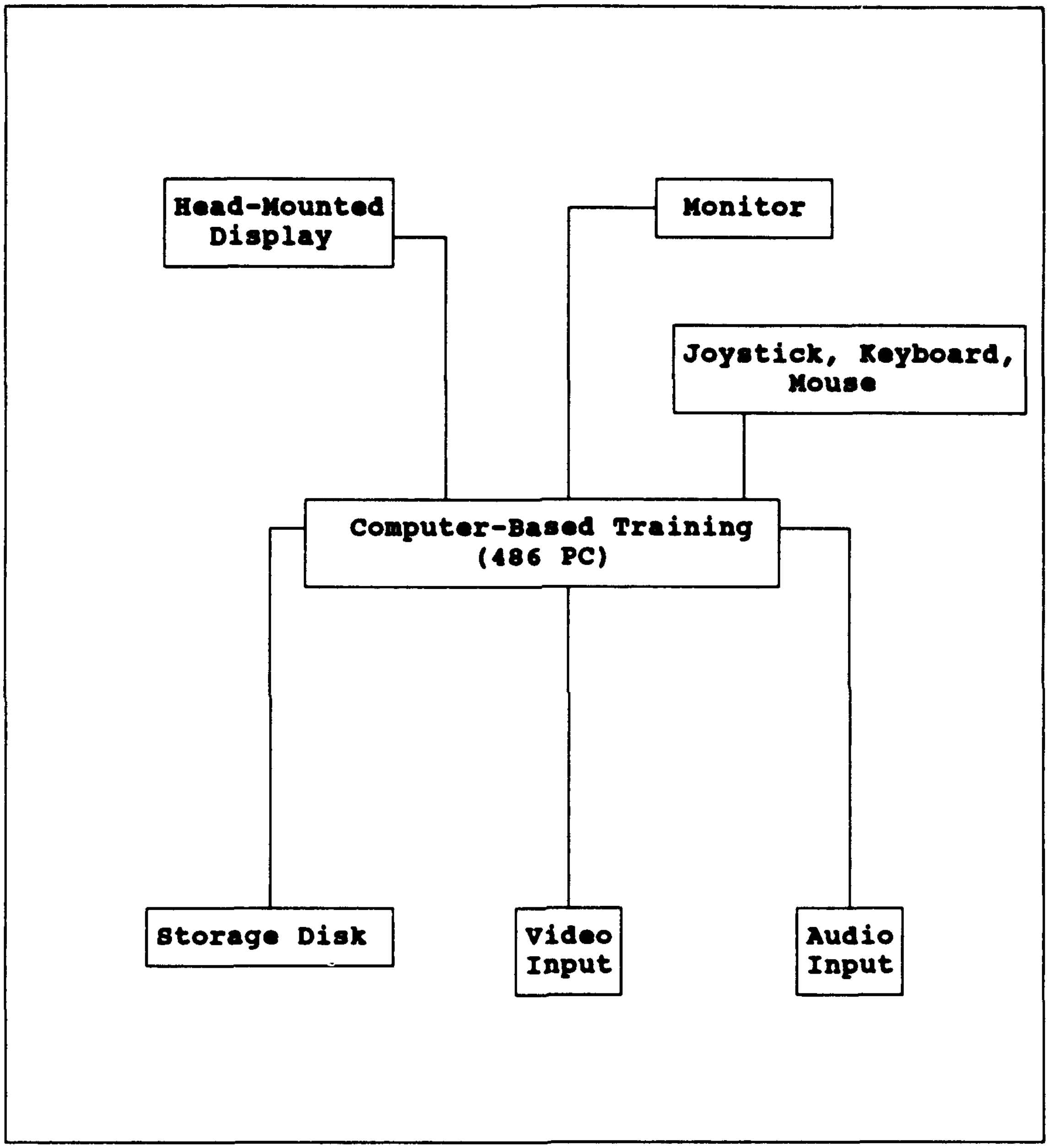

Figure 1. PC-Based Configuration

b. Workstation-Based

Traditionally, workstations have been employed for scientific and engineering applications. Their processing power, memory capacity and displays have been superior to available personal computers. This technology gap has been significantly reduced in the past few years, but the workstation is still able to deliver superior graphical simulation. Silicon Graphics has captured a large market share and is the industry standard in graphics presentation. Since realistic simulation may be a critical element of this CBT, the workstation option must be seriously considered.

Most available workstations have standard memory, speed and graphic capabilities that meet our system requirements. Figure 2 on the next page is a possible workstation-based hardware configuration.

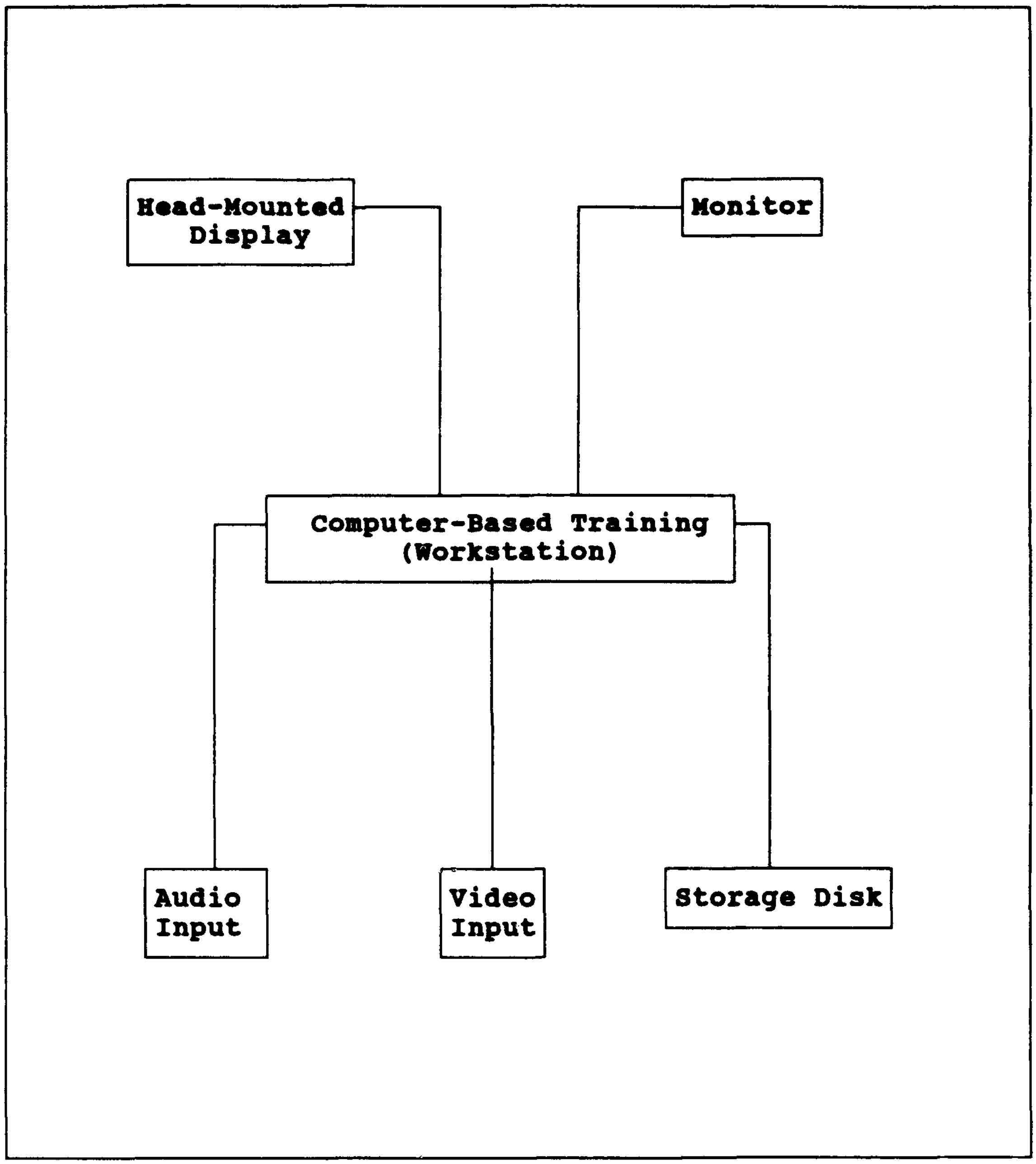

Figure 2. Workstation-Based Configuration

2. Define Functional Components

a. *Personal Computer*

(1) Component Architecture. Available components include an Intel 486 chip with a co-processor for performing complex mathematical functions; an internal disk drive with at least 250 megabytes of storage; a dedicated graphics processor/accelerator with 24-bit color, two megabytes of video RAM (VRAM) to provide dedicated graphics processing and supply a refresh rate of at least 20-30 Hz, full screen; a 256k processor cache to assist CPU processing; a video board that can capture (access) video from a variety of sources (i.e., 8mm video tape, laserdisk, super VHS) and retrieve both real-time and from storage; a 32-bit VESA local bus (VL-Bus) to supplement the graphics accelerator; and an audio card that is compatible with audio CD\ROM and digital audio tapes (DAT).

Three available CPUs for a 486 computer are DX-33 MHz, DX-50 MHz and DX2-66 MHz.

On initial examination, it would appear that the 66 MHz clock speed is most desirable. However, because it is a DX2 configuration, the CPU runs at 66 MHz, but the mother board, which performs the applications, runs at only 33 MHZ. In other words, the computing instructions are collected and performed at 66 MHz, while the data transfer is accomplished at 33 MHz.

The 50 MHz machine has a CPU and a motherboard that both perform at 50 MHz. This allows more uniform processing in computing functions and an overall increase in performance.

Eight to 16 megabytes of random access memory (RAM) should provide the necessary memory space required by the system. Additionally, an operating system that can access this extended memory, such as IBM's OS-2 2.0 or Microsoft's Windows NT, would optimize memory storage and provide for an enhanced, multi-media presentation.

(2) Monitor. A high-resolution, non-interlaced (reduced flicker), 17", SVGA monitor is prescribed. It can support a resolution of up to 1200 x 1024 pixels and up to 16.7 million colors, though not in combination. A larger, flat screen monitor that reduces the amount of glare is also preferable, though not required. The resolution and refresh rate may be critical for realistic simulation. Most can support a refresh rate of at least 60 Hz, depending on screen window size.

(3) Head-Mounted Display. The display must refresh at the same rate as the monitor, for presentation continuity. The size and weight should be representative of the night-vision goggles currently employed operationally, with color capability and similar field-of-view (FOV).

(4) Peripherals. There are a number of peripherals that may provide the required performance. The following discussion will focus on memory storage and audio and video inputs.

A 12" optical laserdisk which normally has a capacity of five gigabytes of data storage should supply the required external memory requirements. Write-once, read-many (WORM) technology allows for specific data mastering and storage, and retrieval when necessary.

Video input sources to the simulation include 8mm, video laserdisk, VHS and CD\ROM. A video capture board that is compatible with all of these sources would be required. Most have the capability of accessing the video real-time and retrieving compressed, stored data from an internal digital file.

Audio input sources include both audio CD\ROM and digital audio tape (DAT). They afford greater memory storage, smoother signal retrieval with reduced audio distortion.

b. Workstation

(1) Component Architecture. CPU speeds range from 33 to 150 MHz. These speeds should produce the required processing power, depending on the application. Obviously, a higher speed is preferable. Internal memory of 16 megabytes and a hard disk size of 300 megabytes are somewhat standard on

most workstations and are appropriate baselines for delivering required performance.

Graphical presentation are often measured in polygons/second in a 10 by 10 pixel box, triangle mesh in a five by 10 pixel box, both in full, 24-bit color, and three-dimensional vectors. Baseline numbers are difficult to determine because the values decrease as the screen size increases. Comparisons must be made on equivalent screen sizes. Full screen refresh normally at least 30 Hz, depending on window size and application.

(2) Monitor. A minimum size of 17" would take advantage of the resolution capabilities of most workstations. They are available with 24-bit color (2^{24} number of colors) and 1280 by 1024 pixels.

(3) Head-Mounted Display. Requirements are the same as for the PC. The displays that were surveyed had connection capabilities with both personal computers and workstations.

(4) Peripherals. The peripherals described previously in the discussion of personal computers are also applicable to the workstation configuration.

3. Tabulate and Compare Capabilities and Cost

Two tables have been constructed. Appendix A contains the information on personal computers while Appendix B contains the information for workstations.

These tables are the foundation for a cost/benefit analysis that is completed in the next step. Price ranges and baseline capabilities are provided, and specific products are described periodically to help the reader. For instance, the head-mounted display chosen is the Kaiser Electro-Optics Sim Eye 40 and for the workstation, the Silicon Graphics Iris Indigo XL.

a. *Configuration Comparison*

Comparing the two configurations, we can refer to Appendix A and B for baseline capabilities and prices. The price ranges provided for the PC system are rough estimates based on numerous brand names. Various discounts are often available for bulk purchase and the Government Service Administration (GSA) provides specific pricing for products from many vendors.

The Iris Indigo2 XL lists at $17,995 [Ref. 8: p.1]. Discounts are available. For example, the Naval Postgraduate School receives a 35% reduction in list price for this unit.

It has a base memory is 32 megabytes, a CPU clock speed of 100 MHz and a hard disk size of 1 gigabyte. Additionally, a 17 inch, 24-bit color monitor is provided in the price. The graphics capabilities include 1280 by 1024 resolution and a maximum refresh rate of 60 Hz.

Prices of personal computers varies greatly among commercial vendors. For a 486-50 MHz machine with 16

megabytes of RAM, a hard disk size of 250 megabyte and a VL-bus can cost between $1,400 and $2,000. Audio and video boards vary greatly, depending on performance qualities. Audio boards for CD\ROM and DAT can cost between $200-$400 and video boards that are able to capture inputs from various sources range from $300-$1,000. Additionally, a dedicated graphics processor/accelerator can range in price from $200-$900. A 17 inch, non-interlaced monitor that can support 1280 by 1024 pixels can cost $1,250.

Prices for peripherals also vary. Once specific performance requirements are determined, a more definite price structure can be designed.

As described, the workstation performance capabilities exceed the pc. The trade-off is cost. Though cheaper, the pc must be provided with add-on features such as video and audio boards.

Reliability is a factor. Name-brand personal computer vendors (i.e., IBM, Dell, Compaq) tend to supply better warranties and readily available maintenance facilities. Many workstation vendors are very established in the market and pride themselves on performance dependability.

b. Software Concerns

In order to address the software concerns evident in the evaluation criteria, a very simplistic software

configuration design is offered to help describe the correlation between the subsystems.

The authoring system is the software integrator. It directly receives inputs from the users and distributes those commands to the various subsytems. It provides diagnostic capabilities and supports window managers and managerial assistance tools such as expert systems and artificial intelligence.

Hypertext acts as a linking mechanism for the audio and video control software. It provides a "point and click" function to assist users in accessing various information such as tutorials and help menus.

The DBMS manipulates the database, when directed by the authoring system, and provides the appropriated information to the simulation software.

The simulation software operates with the graphics generation software to deliver the prescribed presentation requested by the authoring system. This presentation is the displayed simulation.

Figure 3 on the following page depicts the software design.

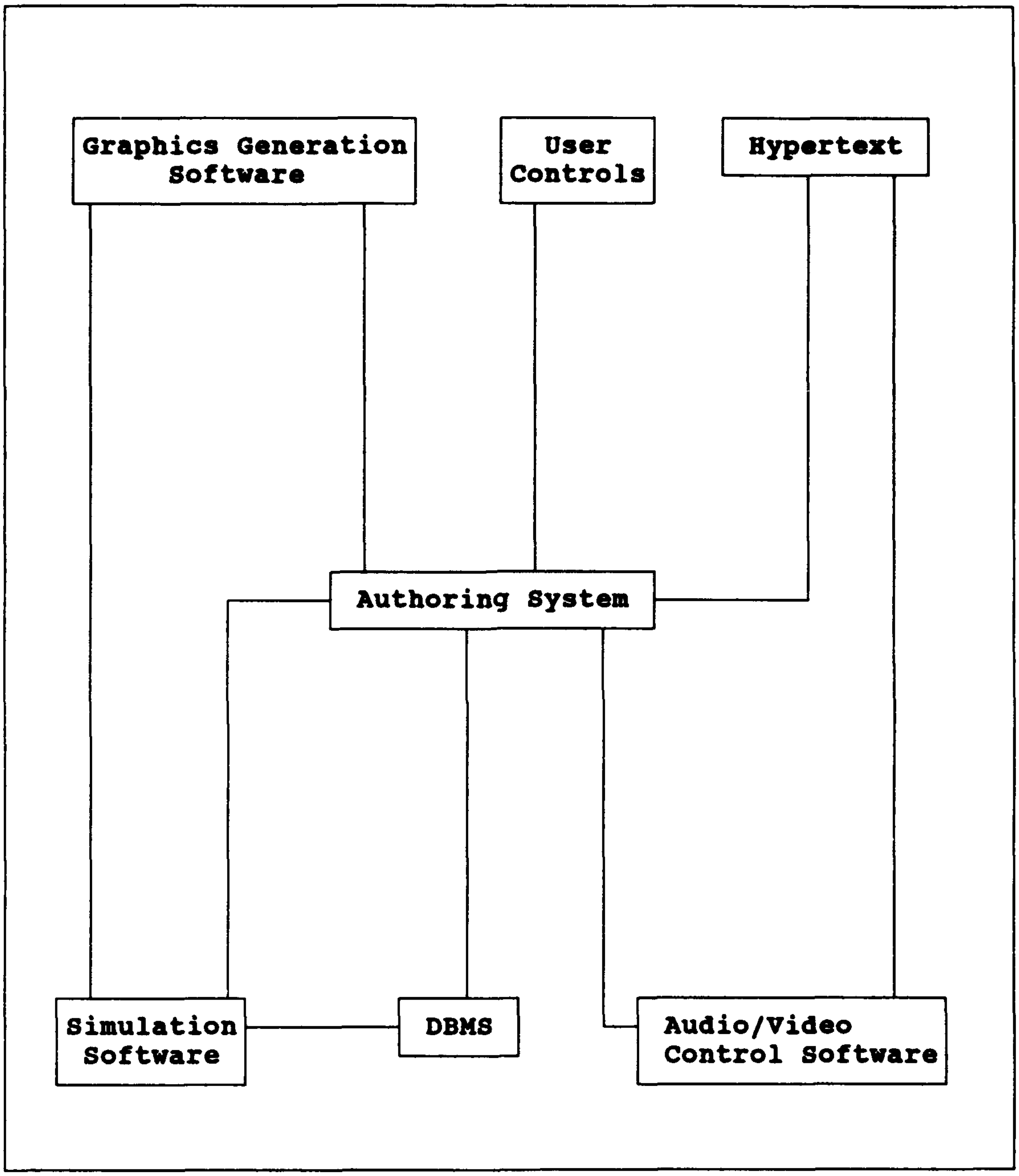

Figure 3. Software Configuration

The building of a representative database or employment of an existing one, must be accurate and the resultant graphics generated, displayed and updated quick enough to provide the required realism.

A basic software summary table, without any representative values, is contained in Appendix C. It has been designed to apply some of the evaluation criteria and assist in the selection process.

4. Selection Process

a. Capabilities Versus Specifications

The two alternative configurations are capable of meeting the current specifications.

As previously discussed, the workstation generally has greater display capability, but a PC can present a graphical display that may prove more than adequate. Until reviewed by the users, both may be capable of delivering the required realism.

Because of the peripheral storage space available to both configurations and the internal memory capacity, a night vision database, once developed, could be integrated into the personal computer and the workstation. Until then, a video source would have to be supplied, such as full-motion video. Both alternatives support this option.

The alternatives presented are compatible with the head-mounted display used in the practical example (the Sim-

Eye from Kaiser Electro-Optical). It can be assumed that other head-mounted displays will also be compatible.

Transportation of the two configurations can be accomplished with very little effort. However, care must be exercised when packing and moving the head-mounted display. The Sim-Eye was relatively fragile and would require detailed packing procedures before transport.

Finally, both configurations meet the constraints of system delivery and complexity. They can be tailored to meet specific user requirements and are currently available on the commercial market.

However, until defined, cost will remain a variable in the selection process. As noted earlier, the workstation configuration cost more but delivers greater performance. Once a cost figure is determined, a final judgement can be made on this constraint.

b. Evaluation Criteria

Applying the evaluation criteria to the identified alternatives and in conjunction with the comparison tables, will ensure that the system selected maximizes benefit and minimizes costs and risk. The specifications described in the criteria, though not rigid, provide a reference for the selector(s) to recognize the most appropriate candidate.

c. *Subjective Measurements*

While cost is an extremely objective measure, other factors are not. Both benefit and risk sometimes require subjective measurements. What might be beneficial for one group of users is not for others. In order to reach a consensus among users, subjective factors must be quantified, at least partially. Assigning relative weight factors sometimes enable the selection process to become more objective. Although not always successful, it should be attempted.

C. SUMMARY

This example has given some basic guidelines to follow in order to apply the framework. Though cursory in nature, this illustration helped to demonstrate the ease of using the straightforward four-step process. An actual selection determination was not provided because of uncertain user requirements, but the tabulated information helped to display the various performance capabilities that currently exist, as well as their associated costs. A direct comparison between alternatives help to clarify some of the pertinent issues that the applicable decision makers must resolve.

V. CONCLUSIONS AND RECOMMENDATIONS

A. REVIEW

1. Design Concerns

Chapter II provided insight into some of the issues related to this system. Uncertain user requirements, possible specification changes and short developmental time-frame restrictions must all be addressed. A review of current simulator techniques, computer technology trends and the emphasis on off-the-shelf procurement provided elaboration to the discussion. Finally, a methodology was described and detailed. It followed a progression from specification definition to possible alternative design.

2. Framework

Chapter III introduced the framework and described possible evaluation criteria. The list of criteria entails revision as technology and requirements change. The framework consist of four basic steps:

1. Identify Alternative Configurations
2. Define Functional Components
3. Tabulate and Compare Capabilities and Cost
4. Selection Process

3. Application of Framework

Chapter IV presented an application of the framework. Collected data on both personal computers and workstations was presented. This information contained target technical capabilities and cost ranges. The example clarified how the framework could be applied to make qualitative decisions on alternative systems and assist in the selection process.

B. FUTURE ENHANCEMENTS

There are many computer components and capabilities that could potentially supplement this CBT. Three possible enhancements are discussed and they all may be available for integration in the system development.

1. Pentium

Noted earlier, personal computers are continuing to bridge the technology gap with workstations. The Pentium processor, rated at either 60 or 66 MHz, employs much faster processing, in some cases by a factor of 10. Consequently, any personal computer decision must include compatibility with the Pentium for upgrade possibilities. Estimated cost for adding the Pentium chip is about half the cost of purchasing a new Pentium system.

2. RISC

An additional upgrade for the personal computer is the employment of the reduced instruction set chip (RISC). Currently employed in most workstations, the RISC processes

the most important instructions, instead of all the instructions, thus reducing access time, increasing the data transfer rate and significantly increasing overall system performance. OS-2 2.0 and Windows NT work across both CISC and RISC platforms.

3. Networking

Although designed to be a stand-alone system when deployed, this desktop CBT could be connected to other available systems, if feasible. This would maximize training for multiple users by providing an avenue for improving flight-lead/wingman discipline.

4. Improvements in Head-Mounted Displays and Display Technology

As technology continues to develop, improvements to head-mounted displays will be realized. Upgraded capabilities in the areas of increased field-of-view and resolution will provide the aircrew with state-of-the-art simulation. Head-mounted devices that integrate all visual cues, whether day or night, are currently in development and virtual reality displays, in the form of wrap-around goggles, are potential future components.

C. RECOMMENDATIONS

1. User Requirements

Operating this system will directly challenge the participating aircrew. Many have never operated even the most rudimentary computer system and those that have usually restrict their usage to word processing applications. Heavy emphasis must be placed on gathering user requirements. Without their direct input in the design and implementation phases, overall system failure may result due to lack of usage. Naval aviation traditionally prides itself on its ability to overcome and master any environment. However, most aviators devote little time to projects that are designed and developed without their direct user input.

Elements requiring special attention include ease of use/training; a low mean time between failure (MTBF); a high quality of vendor support, especially in the initial delivery; and the ability to tailor the simulation to specific operational profiles.

Once the user requirements have been determined, a comprehensive cost\benefit analysis can be conducted utilizing the framework previously discussed. Using the possible baseline values presented in our analysis, commercial vendors can be contacted and prices negotiated for military and/or bulk discounts. The current emphasis on procuring of off-the-shelf products lends itself to our benefit. This CBT could be

designed, prototyped and refined quickly, making it available to operational units in less time.

2. Continual Framework Revision

As computer technology continues to advance, it is extremely important that the prescribed framework be revised to fit the technological growth. The inherent simplicity allows for review and amendment. Since it is operating in a highly-dynamic environment, the framework must respond to the intrinsic progression of computer technology if it is going to remain a viable.

D. CONCLUSIONS

There is no doubt that the hardware exists for constructing this desktop CBT. The lack of a representative night vision database may cause delay in software design, but other means can be employed to at least provide a rudimentary presentation until a realistic database could be integrated. The guidelines discussed have presented a framework to gather specific information essential in comparing various technologies. The amount of commercial vendors, easily accessible literature and an express desire among vendors to participate in defense programs combine to make this CBT extremely viable.

It would be easy to say that cost is the most restrictive factor. If that were true, then the cheapest alternative, with minimum capabilities would be selected. That, however,

should not be the case. Concern about future upgrade capability is a valid one and often less sophisticated (cheaper) systems have little or no upgrade options. However, realistic pricing concerns must be addressed because of the fiscal climate that exists within the Department of Defense, especially in the area of procurement.

Other methods, outside of cost, exist to make an evaluation in preparation for acquisition. Overall technical excellence, detailed scheduling and delivery plans and quality management all have attractive benefits. Combining all these methods, including cost, would allow for a comprehensive approach to development, implementation and maintenance.

The question of "how much is enough" is difficult to answer. Because this system has yet to be constructed and certain design requirements are uncertain, especially night-vision database design, it is hard to set specific performance standards. What we have done is set baseline criteria that provide preliminary performance goals. The two alternative configurations presented both have attractive features. While the PC is less costly, it performs at a reduced rate compared to the workstation. However, the workstation is more expensive, though perhaps more reliable. Choosing between the two will require determining trade-offs in performance, cost, reliability and maintenance. All these variables must be factored into the final decision.

What is most appealing about the desktop CBT concept is that it offers a less costly alternative to large scale simulation. Whether PC or workstation-based, it has unique deployability features and it offers training opportunities where none have previously existed.

If naval aviation is going to survive, it must maximize every opportunity to train, especially while deployed. What better way to comply than to develop a well-designed and upgradable desktop CBT; one that prepares aircrew for the labor-intensive and dynamic mission of low-level navigation employing night vision goggles.

APPENDIX A: TABULATED INFORMATION FOR PC-BASED SYSTEM

486 PC	
	Cost: $1,400-$2,000
	RAM: 16 MB
	CPU: 50 Mhz
	VL-Bus: Yes
	Processor Cache: 256 K
	Hard Disk Size: 250 MB
Audio Board	
	Cost: $200-$400
	Compatible w/CD-ROM & DAT: Yes
Video Board	
	Cost: $1000
	Capture Elements: 8mm,CD\ROM,SVHS,LaserD.
Graphics Processor	
	Cost: $200-$900
	Memory: 2 MB Video RAM (VRAM)
	Bit Color: 24
	3-D?: Yes

APPENDIX A (Cont.)

PERIPHERALS		
Monitor		
	Cost: $1,250	
	Size: 17 inch	
	Interlaced/Non-Interlaced: NI	
	Resolution: 1280 by 1024	
	Available Colors: 256 (full screen)	
Head-Mounted Display		
	Cost: $95,000; Bulk discounts available	
	LCD/Fiber Optic: LCD	
	Field of View (FOV): 40 V by 60 H degree	
	Refresh Rate: 60 Hz maximum	
	Monochrome/Color: Both	
Video Input Device		
	Type: VCR	Type: Laserdisk
	Cost: $300-$700	Cost: $400-$1,200
Audio Input Device		
	Type: CD\ROM	Type: DAT
	Cost: $200-$500	Cost: $300-$500
Storage Disk		
	Cost: $4,000-$6,000	
	Memory: 5 GB	

APPENDIX B: TABULATED INFORMATION FOR WORKSTATION-BASED SYSTEM

Workstation	
	Cost: $17,995 (List)
	SpecInt92/SpecFP92: 58.6/60.6
	Base Memory Size: 16 MB
	Hard Disk Size: 1 GB
	UNIX Compatible: Yes, IRIX supplied
Graphics Capability	
	Full Screen Refresh Rate: 60 Hz
	3-D Vectors: 490 K
	Polygon/Sec: 60 K
	T Mesh: 40 K
Monitor	
	Cost: Included in workstation price
	Size: 17 inch
	Colors (Bits): 24
Peripherals, Excluding Monitor	
	See Appendix A

APPENDIX C: POSSIBLE SOFTWARE REQUIREMENTS

Software Support	Authoring Tool:
	Cost:
	Diagnostic Capabilities:
	Window Manager Support?:
	Support for AI/Expert System Shells?:
	Visual Database Tool:
	Cost:
	Access/Rendering of DMA/USGA Terrain Data?:
	Symbology Tool:
	Cost:

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